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HENRY EDWARD CRAMPTON

PROFESSOR OF ZOOLOGY
COLUMBIA UNIVERSITY

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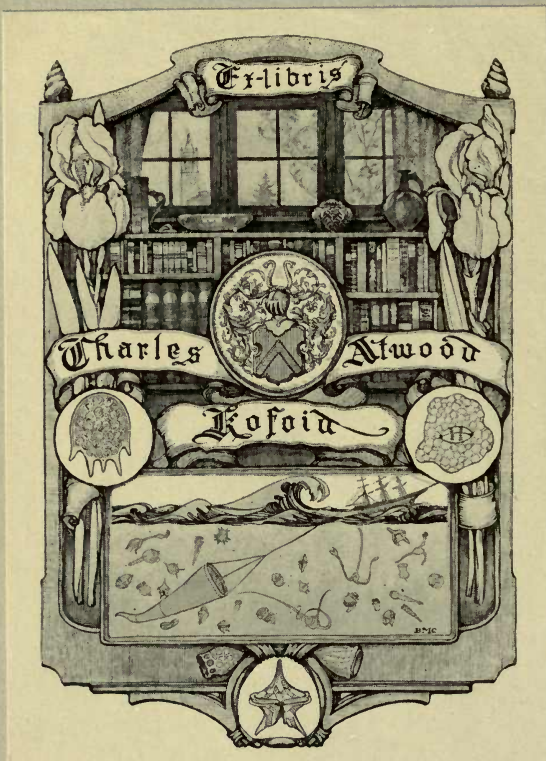
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In the present series of addresses upon the nature and scope of some of the divisions of knowledge, zoology connects the natural sciences with those subjects that deal with human progress in physical, social, political and economic respects. Like the human and other sciences, zoology has arisen from that vague uncoördinated and unresolved mass of knowledge, the Natural Philosophy of not very remote times, which undertook to comprehend all there was of nature and thought. And again like the other sciences it is as such a branch of relatively late growth. In earlier times few men were sufficiently withdrawn from the affairs of the market-place and commerce and conquest, from politics and government and theological propaganda, to observe the phenomena of nature closely, to reflect upon their observations, and to summarize their deductions in the formularies of natural law. Not until human social structure neared the relatively settled condition of modern times did it become possible for men to differentiate as students of nature solely, rendering their service to the common weal as investigators of the less practical and more remote departments of knowledge. Now the sciences have become so great, so complex and varied, that it is impossible for a single mind to comprehend all that is included in one of them. So widely the impelling energy of research has driven the soldiers of investigation that only when, as in the present series of addresses, they return to the council-fires of an intellectual

bivouac can they come to realize how far-flung indeed are the battle-lines of the armies of science—how rich and diversified is the territory from which knowledge has driven ignorance and superstition. And they must realize also how impossible it is for them to conduct their operations at all times in entire independence. The results of physics and chemistry are indispensable weapons for the biologist; geology takes the field with paleontology for the study of fossil forms; while on the other hand the advance posts of zoology provide the students of many a human science with a secure base of operations.

I need not speak of the inter-relations of the several biological sciences, for these have been sufficiently explained in the earlier discourses. I shall pass directly to a description of the elements of the present science of zoology and of its history, so far as this is necessary for a clear understanding of the various divisions of the subject and of their connections; and finally I shall endeavor to show how through its human materials zoology articulates directly with other fields of knowledge.

ZOOLOGY is the science that deals with the structure, development and inter-relationships of animals, with the workings of their parts, their activities and their relations to their environment, and with the factors that determine their forms. We may recognize two great divisions of the subject, which are concerned respectively with static and with dynamic principles, though the materials of both divisions are the same—namely, all animals throughout the entire range from the highest to the lowest. It is of course clear that morphology—the science of structure—cannot be absolutely separated from physiology—the science of function in its widest sense—for we do not know of organic structures that play absolutely no part in an animal's

economy, even though this may be a relatively passive one; while on the other hand we do not know—in science at any rate—of a function that is devoid of a material basis. The division is made solely for the sake of analysis, and it depends entirely upon the point of view. Morphology treats adult animals, their different developmental stages, and, more naturally, the remains of extinct animals as though they were arrested in their living, but the dynamic aspects of organic life are so prominent and insistent that it is really impossible to ignore them even temporarily.

Besides dealing with the same materials, the many complicated problems of zoology are still further connected in that the central object of study for both the structural and physiological divisions is evolution. As we look back over the history of the subject from our modern vantage-ground, we can see how zoology began with ancient and mediaeval natural history, how from this parent stock arose the additional separate branches of anatomy, embryology, paleontology and distribution, how human physiology became comparative physiology which developed later into the broad and deep enquiry into all the activities of animals, their vital relations to one another, and their reactions to and upon the environment; and we can see how all these several branches were vitalized by the great principle of evolution. This whole history shows a steady progress through one phase after another toward the modern study of evolution, though the naturalists of the eighteenth and even of much of the nineteenth century were unconscious, in whole or in part, of the way their observations and views were contributing to the establishment of the doctrine of descent and to the partial description that can now be offered of the natural factors of evolution. As we shall see, the structural analysis of animals demonstrates the evolution of species as a universal process, while the broad study of the dynamic relations of

animals is concerned with the causes of this process, as what we may venture to call the physiology of evolution. In brief, then, the great questions of zoology are the *what* and the *how* of evolution.

In view of the earlier lectures, it is unnecessary to speak at length of classification or taxonomy—the first division of static or structural zoology. Aristotle, who gathered and studied some five hundred of the more common animals of the earth and shore and sea, and the mediaevalists Wotton and Ray, Gesner and Aldrovandi, were animated primarily by the instincts of the collector of interesting information. Linnaeus, the great figure of the eighteenth century, rendered an immortal service to zoology (and botany, too,) by introducing the present ordered system of naming and classifying organisms. But classification was to Linnaeus an end in itself, he could not see that it was but a means to the larger end of understanding and expressing evolutionary relationships,—that resemblance meant consanguinity. It remained for Erasmus Darwin, the elder St. Hiliare, Lamarck and others to appreciate this inner meaning which so vivifies the otherwise dead details of taxonomy.

The many connected details of animal structure and development and function constitute the threads, as it were, which are interwoven by comparative treatment to form the warp and woof of the fabric of zoology. Classification draws upon this fabric the pattern of genealogical connections, emphasizing those threads that run furthest, the so-called distinctive or diagnostic characters. And though the pattern must be altered here and there as knowledge increases, the zoologist feels that it has a real significance as a representation of evolutionary descent.

As more and more of the lower animals were brought by the microscope from the obscurity of their zoological underworld, as exploration revealed more of the creatures

of previously unknown lands, as investigation became more detailed and intensive, comparative anatomy arose as an independent branch of zoology with distinct purposes of its own; and it gained its specific form and character from the studies of the great zoologists of the early nineteenth century—Lamarck, Cuvier, Geoffroy St. Hiliare, Goethe, Owen, and Oken. These naturalists dissected and compared the various organic systems of animals, following them as widely as possible from group to group of the numerous vertebrate and invertebrate forms, and they and their followers have placed the doctrine of evolution upon the sure and broad foundation of comparative anatomy. The main principle of this department of zoology is that the varied forms of animals exhibit deep-seated likenesses that place them in groups related to one another not as the rungs of a ladder as Lamarck supposed, but rather as the branches of a tree or a bush; and such branches again like those of a tree bear smaller branches, and these reach to lesser or greater heights from the base level of primitive organization. Thus, anatomy holds that community of plan is an indication of genetic affinities, while modifications of a common plan exhibit the results of adaptation to different ends through evolution, The framework of the human arm is constructed out of the same elements with the same arrangement that we find in the leg of a cat, the flipper of a seal, the paddle of a whale, and even the wing of a bat, different though these structures are in function,—and in these resemblances comparative anatomy discerns evidence of a remote common ancestry of men and whales and bats.

Extended through the study of tissues, or histology, to the unitary elements of organic structure—the cells—comparative analysis has brought the whole realm of organic nature under the sway of a great principle—the cell-doctrine of the botanist Schleiden and the zoologist

Schwann. This important principle, propounded in 1838 and 1839, produced an immediate effect in unifying organic creatures, though many years passed before it was formulated in the terms employed to-day. In brief, it is this:—All the larger organisms are composed of organs which in turn are constructed of various tissues, like muscle and nerve and connective elements; the tissues finally can be resolved into units of structure, the cells, which agree in possessing a central body or nucleus, and in their protoplasmic substance. The elementary nature of cells is still further demonstrated by the simplest organisms we know, which consist of one cell, nothing more and nothing less; while finally the starting point in the development of higher animals is always a single cell—the egg. Truly these are remarkable facts, when we consider the wide range of animal and plant forms.

Vast as the present knowledge is, the tasks of comparative anatomy are not entirely completed. Though voyages of exploration like those of the *Beagle* with Darwin, the *Rattlesnake* with Huxley, and above all of the famous *Challenger* have gone to all parts of the globe, though countless investigators have devoted their lives to the study of special groups like birds and mammals and insects and molluscs, every year brings to light new forms that must be analyzed and placed; while new discoveries in other departments often make it necessary to re-examine known series in the light of fuller knowledge.

While many naturalists prior to the nineteenth century were interested in the way an animal egg produced an adult organism, it was not until the doctrine of descent energized zoology that comparative embryology attained the independent status that it holds to this day. Harvey in 1650 had perceived that, in his own words, "all animals are in some sort produced from eggs." Bonnet and Haller, of the early eighteenth century, contended that the germ was

a minute replica of the adult which formed it, a *multum in parvo* which simply unfolded and enlarged to produce another adult organism; Wolff, however, showed that this view lacked a basis in fact, and that as we now universally believe, embryonic history is a true development from the simple and unorganized to the progressively more and more specialized later conditions,—that it is, in a word, an epigenesis. The great name of the infancy of embryology is that of Von Baer (1792–1876). This acute observer and thinker was struck by the similarity of early stages in the development of quite different adult animals. Birds and reptiles and even mammals pass through stages when they possess gill-slits like those of fishes, related to heart and blood-vessels like the similar structures in lower vertebrates; butterflies and flies and beetles are somewhat alike in their larval stages, when as caterpillars and maggots and grubs they not only resemble one another remarkably but they are also very like worms. Under the influence of the evolution doctrine, then becoming more generally accepted, Von Baer and a host of followers extended the science of comparative embryology until Haeckel in 1866 ventured to state the "Law of Recapitulation," or the "Biogenetic Law," in the following rigid terms:—Ontogeny recapitulates Phylogeny. (The development of an individual reviews the past history of its species.) Led by their enthusiasm many of the later nineteenth century zoologists followed too implicitly the lines of the embryonic record, though Haeckel himself, the most radical advocate of the law, pointed out that there are many serious omissions in the narrative, that false passages are inserted as the result of purely larval and embryonic needs and adaptations, while many alterations in the way of anachronisms have been made. Of late years there has been a strong reaction from the complete acceptance of the principle as a reliable mode of interpreting embryonic histories. But I believe

zoologists generally feel that used with due caution the law has a high value for the student of evolution, and they realize that embryology is perhaps more significant in other respects than in showing exactly how in past times any given species has evolved. The present tasks in this department, now so thoroughly investigated, are to distinguish between the false and the true portions of the record, between the new and the old, and to ascertain the physiology of development, in order to gain a more complete knowledge of racial history and of the dynamics of organic nature.

The study of the fossil remains of animal organisms, or paleontology, is the fourth division of structural zoology, which as an independent branch dates back to the time of Cuvier, scarcely a hundred years ago. Vestiges of creation were indeed known long before that time, but they were variously regarded as freaks of geological formation, *lusus naturæ,* as remains of creatures stranded by tidal waves or cataclysms like the traditional flood, or again as the remains of animals formed by a process of spontaneous generation in the depths of the earth that had failed to reach the surface. It was Leonardo da Vinci of the fifteenth century who, anticipating the naturalists of later times, believed these vestiges are what common-sense says they are —simply relics of creatures that lived when the earth was younger. Cuvier was in a true sense the founder of paleontology; though a special creationist, he recognized that beneath their differences there were fundamental likenesses between recent and extinct animals. He assumed that cataclysms had closed the several geologic epochs whereupon new series of animals and plants were created upon the same general working-plans employed in earlier ages; thus he combined the idea of change in geologic time with a belief in supernatural creation. When, however, Lyell led geologists and others to abandon the cataclysmic hypothesis in favor of the doctrine of uniformitarianism, when

the series of known fossil forms increased and the intrinsic value of the paleontological evidence became clearer, the doctrine of evolution finally claimed this field also as its own.

The nature of the case is such that the fossil record must remain incomplete, perhaps forever. For not all the animals of former times possessed hard parts capable of resisting the disintegrating forces of organic and inorganic nature, the rocky tombs of those animals that were embedded in the sands and silts have been crushed and rent asunder by the very geological agencies that at first constructed them. More than half of the earth's surface is now under water, while by no means all of the dry land is accessible. Only a few scratches have been made here and there upon the earth's hard crust, so it is little wonder that the testimony of the rocks is halting and imperfect. But what there is, a rapidly growing body of cold, hard facts, is in itself conclusive evidence of the reality of evolution. Researches like those of Von Zittel, Cope, Hyatt, Marsh, Osborn, and Scott, demonstrate that, when they appear at all, the great groups or *phyla* of animals and their subdivisions succeed one another in that chronological order which comparative anatomy and embryology have independently shown is the order of their evolution. Then too there are those fossil types that link together groups now so widely separated, like *Archaeopteryx,* which is at once a feathered reptile and a bird with reptilian tail and skull and limbs. And there are the marvelously perfect series of fossils like those which demonstrate the evolution of modern horses and elephants; and finally, as the special creationist Louis Agassiz himself showed, some fossil series parallel very closely the embryonic record in modern types. No field opens more invitingly than that of the paleontologist. His tasks are to search the rocks everywhere for new fossil types to fill in the gaps of the lines of

descent that at best can only be interrupted lines, and to show how these lines lead to modern forms or to divergent kinds that have ceased to be. And he will compare his results with those of students in other fields, who will assist him to formulate the working-plans for his own labors.

Zoo-geography is the last branch of structural zoology to attain an independent status. Many observers from Buffon onward had been struck by the fact that species of animals are not uniformly distributed over the earth, that they differ more widely as the observer passes to more and more remote localities, with more different climatic and other environmental conditions. But the meaning of these peculiarities was obscure until the doctrine of descent cleared their vision. Wagner, Louis Agassiz, and Dana, Sclater, Murray, and Wallace were the leaders of those who have brought together the immense mass of modern knowledge of animal distribution. From this many well-established principles relating to descent have been derived, though these have a deeper interest in connection with the dynamic problem as to whether differences in environment can actually cause species to transform, as Lamarck supposed. As a statement of the results in this apparently simple, but really quite complicated field would be misleading, I fear, from its brevity and general form, I will venture to present just one conclusion. Geographical isolation corresponds in a general way with the divergence of species in their evolution from common ancestors; thus widely separated areas have faunas that differ more widely in zoological respects than do those of neighboring or connected countries. For example, the Australian region has been cut off for a relatively long period from neighboring continents, and in correspondence with this isolation it contains the only egg-laying mammals known, as well as all of the pouched mammals like the kangaroo, with a few exceptions like our American opossum. Furthermore, groups

of isolated oceanic islands, like the Galapagos and Azores and the clusters of Polynesia, are inhabited by lizards and birds and insects which resemble most closely the species of the nearest bodies of land. Such resemblances are most reasonably interpreted as indicating that the original progenitors of the island colonies were stragglers from the nearest mainland, whose descendants have undergone divergent evolution during succeeding generations.

Having, then, this vast store of fact and principle amassed through centuries by countless students, the zoologist is entitled to speak positively when he finds a law like the doctrine of evolution that reviews and summarizes the whole range of animal structure. The well-established facts of zoology are the reasons why he asserts with a decision often mistaken for dogmatism that evolution is a real process. The further question, why is nature so constituted that evolution is true, is an enquiry that does not fall within the limits of zoological science.

We now come to the second great division of zoology, which as a whole is concerned with broad and deep enquiry into the workings of nature; it is natural history in the best sense. Prior to the time of Darwin attempts to solve the kinetic problems of the organic world were hampered by anthropomorphism and narrowness of view, as well as by paucity of facts. But since then, owing to the immense influence of the works of that great naturalist, so much attention has been given to the fundamental problems of life that it is now possible to correlate many principles which describe not only the *fact* of evolution but many of the *factors* as well. And in this modern development wide observation has led so directly to extensive experiment that we may justly characterize the present period as an age of experimental zoology. Just as all the apparently disconnected studies of structural zoology deal with one matter,—evolution,—so in the sphere of experimental zoology

all the radii converge upon the study of the factors and method of species transformation.

We can only mention some of the modern departments which have yielded brilliant results, such as cytology, experimental embryology, experimental fertilization, and regeneration. But we may point out that the general problems in these various fields deal like the problem of evolution itself with an analysis of the internal and external influences that determine the final adult conditions of species. For example, the adult salamander possesses a specific structure, in a state of balance or adaptation, that is the final result of an evolution process up to the present time; this same specific condition is the goal of the changes through which the salamander's egg and embryo pass in development; it is the goal also that may be reached by even a portion of a divided salamander's egg; while finally it is the goal of the regenerative processes that enable a salamander from which a leg has been cut off to reproduce the missing part. Everything centers then about the question as to the origin of adult specific forms, which exhibit adaptation.

Realizing this, we may pass on immediately to consider how through the study of adaptation, Darwin was led to formulate his potent theories, which have been the basis for recent progress. As the other speakers upon biological sciences have already stated, the most striking feature of animals and plants is their adjustment to their vital conditions. An organism that seems so sufficient unto itself, so capable and independent, is nevertheless inextricably interlocked with its surroundings, for its very substance is composed of materials which with their endowments of energy have been wrested from the environment. An animal that is pressed upon by the substances of the outer world, that is played upon by various energies, and is attacked on all sides by innumerable foes, finds itself in-

volved in a warfare that is tragically one-sided; and it must prevail over all its many foes or it must acknowledge defeat and pay the penalty for unconditional surrender, which is death,—so stern and unyielding is that vast totality we individualize as the environment. The generalized biological formula, then, for the turmoil of nature is *adaptation=life.*

Here then is the heart of the mystery. How has this universal condition of adaptation been brought about? What have animals within them that might determine their greater or less efficiency? What external influences, if any, are capable of directing the efforts of living creatures to meet their enemies? How are modifications perpetuated when they have arisen? To many of these questions Darwin, Weismann, Mendel, De Vries, and others have found answers, not complete or perfect, it is true, but they have relegated to the past the former reply that supernatural causes must be invoked to account for nature. Science is convinced that the study of nature's workings at the present time reveals natural factors which are competent to account for much of the wonderful process of evolution.

As everyone knows, the works of Darwin inaugurated our recent era in biology. In 1858, Darwin and Wallace announced the doctrine of natural selection, and in 1859, Darwin published the "Origin of Species," a book that has proved a veritable Magna Charta of intellectual liberties, for as no other single document before or since it has released the thoughts of men from the trammels of unreasoned conservatism and dogmatism. And its influence has been felt far beyond the borders of biological science—it has extended to the very confines of organized knowledge everywhere. But it is a mistaken popular notion, and one of the hardest to drive from the mind of the layman in science, that Darwin founded the doctrine of evolution by the book

mentioned and those that followed. The fact of evolutionary descent had been established long before, while even some of the special points of Darwin's theories as to method had been anticipated. Had Darwin never lived, I believe that evolution would still be accepted and taught at the present day. But Darwin rendered two immortal services to science. During the twenty years that elapsed between the first conception of his theories and the date of their publication, he marshalled in orderly array all the biological data obtainable which proved the transformation of species, including the previously unrecognized body of evidence afforded by the domesticated animals. In the second place, in his doctrine of natural selection he presented for the first time a partial consistent program of nature's method of accomplishing evolution. Darwin did not believe that this explanation was final or even complete, whatever his opponents of the time or critics of the present might contend.

What now, is the doctrine of natural selection, as Darwin propounded it? All animals vary; every individual differs from others of its kind, even from its closest kin and from its parents in some or many particulars and to different degrees. Whatever the causes, the fact of variation stands unquestioned. Some variations are of course due to direct environmental influence, and to these Buffon attributed an excessive importance; other deviations from the parental or average specific type are no doubt due to indirect effects of the environment, as Lamarck contended. But there are countless other variations that cannot be so explained, some of them indeed appearing before an individual is subjected to the action of the environment, and these are the congenital variations due to some constitutional even if unknown causes. These seemed to Darwin to be the most important in evolution.

The second element of the doctrine is that over-produc-

tion, or rather over-*re*production, is a universal characteristic of living things. The normal rate of multiplication is such that any given form of animal or plant would cumber the earth or fill the sea in a relatively brief period of time. We now know that a bacillus less than 1/5000 of an inch in length multiplies under normal conditions at a rate that would cause the offspring of a single individual to fill the ocean to the depth of a mile in five days. "Slow-breeding man," wrote Darwin, "has doubled in the past twenty-five years." But excessive multiplication is checked by the third part of the whole process, namely, the struggle for existence, that fierce unequal warfare waged by every individual with its inorganic surroundings, with other species of living things, and with others of its own kind. Indeed where members of the same species compete, the struggle often surpasses in ferocity the warfare with other organisms. Communal organisms only are in part exceptions, for in these the battle involves the clash of community with community more than it does the interests of the individuals of a single colony. To what, now, do these elemental processes lead, asks Darwin. Though all seek to maintain themselves, all cannot possibly live when only a few can find sustenance or can escape their enemies. Naturally those which possess any advantage whatsoever, that vary ever so slightly in the direction of better adjustment would survive where their brethren perish. And this is nature's selective process, with its positive and negative aspects—the survival of the fittest and the elimination of the unfit. Now we can see why adaptation is a universal characteristic of species—there are no unadapted. If such there were, they have fallen long ago, and the world knows them no more. True it is that perfection is not attained by any creature, but it must establish a *modus vivendi* or it perishes. Thus, Darwin held, nature perfects species by dealing directly with favoring derivations that

are mainly congenital, and so through these it selects the hereditary factors that determine favorable variations.

In one fundamental respect the doctrine is incomplete, as it fails to explain the causes for the variations with which selection deals. It accounts for the perpetuation of favoring variations, but it does not account for their inception. Because of this defect, investigators reacted from the academic discussion of Darwin's original doctrine, and returned to deeper and wider study of heredity and variation with brilliant success. Some neo-Darwinians have endeavored to make the selective process an originative influence—notably Roux, and Weismann in his theory of germinal selection. Darwin himself added the subsidiary process of sexual selection, which regards the preference by one sex of characteristics of the opposite sex as a conserving influence. But while such attempts have failed, zoologists believe, to explain the whole method of evolution, much of the process has been demonstrated more and more clearly with further study. The laws of fluctuating variations have now been formulated with mathematical accuracy, through the employment of the statistical methods used earlier by anthropologists like Quetelet. The studies of Galton, and Pearson, Boas, Weldon, and Davenport have demonstrated that structural and physiological characters of men, of other animals, and of plants as well, vary according to the formulas of chance or error, —a result they say that follows from the combined influence of innumerable and independent factors. Variation is a natural phenomenon of chance. Furthermore, the reality of the selective process has also been proved by statistical methods. Bumpus' English sparrows, Weldon's snails and crabs, and many other cases show that the individuals which depart widely from an average condition, or that are uncorrelated in their organization, are marked for destruction.

In brief, while natural selection has not been established as in any sense an originative process, it has been demonstrated, I believe, as a judicial process. For we may liken the many varied vital conditions to jurymen, before whom every organism must present itself for judgment; and a unanimous verdict of complete or at least partial approval must be rendered, or the organism must perish.

The phenomena of biological inheritance, however, have demanded the greater attention of Darwinian and post-Darwinian investigators. A complete statement of the whole of evolution must show how species maintain the same general characteristics through inheritance, how the type is held true with passing generations, and it must also show how new characters may enter into the heritage of any species to be transmitted as organisms transform in evolution.

The earliest naturalists had accepted the fact of inheritance as self-sufficient. The resemblance between parent and offspring did not demand an explanation any more than variation. When Buffon, however, added the element of species transformation, he held that external influences could bring about a directly responsive organic change, which he assumed was inherited. Lamarck developed the well-known view, previously advocated by Erasmus Darwin, that indirect responses to the environment could be fixed in inheritance as so-called "acquired characters," meaning by this phrase that such characters are acquisitions during the life-time of an individual as the effects of disuse or unusual use, or of new habits. Coming again to Darwin, we find that he endeavored to support Lamarck's doctrine and to supplement his doctrine of selection by adding the theory of pangenesis. According to this every cell of every tissue and organ of the body produces minute particles called gemmules, which partake of the characters of the cells that produce them. The

gemmules were supposed to be transported throughout the entire body, and to congregate in the germ-cells, which would be in a sense minute editions of the body which bears them, and would so be capable of producing the same kind of a body. If true, this view would lead to the acceptance of Lamarck's or even Buffon's doctrine, for changes induced in any organ by other than congenital factors could be impressed upon the germ-cell, and would then be transported together with the original specific characters to future generations. Darwin was indeed a good Lamarckian.

But the researches of post-Darwinians, and especially those of the students of cellular phenomena, have demonstrated that such a view has no real basis in fact. Many naturalists like Naegeli and Wiesner were convinced that there was a specific substance concerned with hereditary qualities as in a larger way protoplasm is the physical basis of life. It remained for Weismann to identify this theoretical substance with a specific part of the cell, namely, the deeply-staining substance, or chromatin, contained in the nucleus of every cell. Bringing together the accumulating observations of the numerous cytologysts of his time, and utilizing them for the development of his somewhat speculative theories, Weismann published in 1882 a volume called "The Germ-Plasm," which is an immortal foundation for the later work on inheritance. The essential principles of the germ-plasm theory are somewhat as follows: The chromatin of the nucleus contains the determinants of hereditary qualities. In reproduction, the male sex-cell, which is scarcely more than a minute mass of chromatin provided with a thin coat of protoplasm and a motile organ, fuses with the egg, and the nuclei of the two cells unite to form a double body, which contains equal contributions of chromatin from the two parental organisms. This gives the physical basis for paternal inheri-

tance as well as for maternal inheritance, and it shows why they may be of the same or equivalent degree. When, now, the egg divides, at the first and later cleavages, the chromatin masses or chromosomes contained in the double nucleus are split lengthwise and the twin portions separate to go into the nuclei of the daughter cells. As the same process seems to hold for all the later divisions of the cleavage-cells whose products are destined to be the various tissue elements of the adult body, it follows that all tissue-cells would contain chromatin determinants derived equally from the male and female parents. As of course only the germ-cells of an adult organism pass on to form later generations, and as their content of chromatin is derived not from the sister-organs of the body but from the original fertilized egg, there is a direct stream of the germ-plasm which flows continuously from germ-cell to germ-cell through succeeding generations. This stream, be it noted, does not flow circuitously from egg to adult and then to new germ-cells, but it is direct and continuous, and apparently it cannot pick up any of the body-changes of an acquired nature; indeed, it is doubtful whether such changes can reach the germ-cells at all, for the path is not traversed in that retrograde direction.

It must be clear, I am sure, that this theory supplements natural selection, as it describes the physical basis of inheritance, it demonstrates the efficiency of congenital or germ-plasmal factors of variation in contrast with the Lamarckian factors, and finally in the way that in the view of Weismann it accounts for the origin of variations as the result of the commingling of two differing parental streams of germ-plasm.

At first, for many reasons Weismann's theories did not meet with general acceptance, but during recent years there has been a marked return to many of his positions, mainly as the result of further cytological discov-

eries, and of the formulation of Mendel's Law and of De Vries' Mutation Theory. The first-named law was propounded by Gregor Mendel on the basis of extensive experiments upon plants conducted during many years, from 1860 on, in the obscurity of his monastery garden at Altbrünn, in Germany. It was rescued from oblivion by De Vries who found it buried in a mass of literature and brought it to light when he published his renowned Mutation Theory in 1901. Mendelian phenomena of inheritance, confirmed and extended by numerous workers with plants and animals, prove that in many cases portions of streams of germ-plasm that combine to form the hereditary content of organisms may retain their individuality during embryonic and later development, and that they may emerge in their original purity when the germ-cells destined to form a later generation undergo the preparatory processes called maturation. They demonstrate also the apparent chance nature of the phenomena of inheritance. I think the most striking and significant result in this field is the proof that a particular chromosome or chromatin mass determines a particular character of an adult organism, which is quite a different matter from the reference of all the hereditary characters to all of the chromatin. Professor Wilson has brought forward the convincing data showing that the complex character of sex in insects actually resides in or is determined by particular and definite masses of this wonderful basis of inheritance.

Mendel's principles also account in the most remarkable way for many previously obscure phenomena, such as reversion, and again, the case where a child resembles its grandparent more than either of its parents; these seem to be due, so to speak, to the rise to the surface of a hidden stream of germ-plasm that had flowed for one or many generations beneath its accompanying currents. I believe that the law is replacing more and more the laws of Gal-

ton and Pearson, formulated as statistical summaries of certain phenomena of human inheritance taken *en masse.* According to Galton's celebrated law of ancestral inheritance, the qualities of any organism are determined to the extent of a certain fraction by its two parents taken together as a mid-parent, that a smaller definite fraction is contributed by the grandparents taken together as a mid-grandparent, and so on to earlier generations. But Mendel's Law has far greater definiteness, it explains more accurately the cases of alternative inheritance, and it may be shown to hold for blended and mosaic inheritance as well.

De Vries' Mutation Theory has already been explained in an earlier address by Professor Richards. It is clearly not an alternative but a complementary theory to Natural Selection, the Germ-Plasm and Mendelian Theories. Like these last, it emphasizes the importance of the congenital hereditary qualities contained in the germ-plasm, though unlike the Darwinian doctrine it shows that sometimes new forms may arise by sudden leaps and not necessarily by the slow and gradual accumulation of slight modifications or fluctuations. The mutants like any other variants must present themselves before the jury of environmental circumstances, which passes judgment upon their condition of adaptation, and they too must abide by the verdict that means life or death.

From what has been said of these post-Darwinian discoveries, the Lamarckian doctrine, which teaches that acquired non-congenital characters are transmitted, seems to be ruled out. I would not lead you to believe that the matter is settled. I would say only that the non-transmission of racial mutilations, negative breeding experiments upon mutilated rats and mice, the results of further study of supposedly transmitted immunity to poisons—that all these have led zoologists to render the verdict of "not proved." The future may bring to light positive evidence,

and cases like Brown-Séquard's guinea pigs, and results like those of MacDougal with plants and of Tower with beetles may lead us to alter the opinion stated. But as it stands now most investigators hold that there are strong general grounds for disbelief in the principle, and also that it lacks experimental proof.

The explanation of natural evolution given by Darwinism and the principles of Weismann, Mendel and De Vries, still fails to solve the mystery completely, and appeal has been made to other agencies, even to teleology and to "unknown" and "unknowable" causes as well as to circumstantial factors. A combination of Lamarckian and Darwinian factors has been proposed by Lloyd Morgan, Mark Baldwin, and Professor Osborn, in the Theory of Organic Selection. The Theory of Orthogenesis propounded by Naegeli and Eimer, now gaining much ground, holds that evolution takes place in direct lines of progressive modification, and is not the result of apparent chance. Of these and similar theories, all we can say is that if they are true, they are not so well-substantiated as the ones we have reviewed at greater length.

The task of experimental zoology is to work more extensively and deeply upon inheritance and variation, combining the methods and results of cellular biology, biometrics, and experimental breeding. We may safely predict that great advances will be made during the next few years in analyzing the method of evolution; and that a few decades hence men will look back to the present time as a period of transition like the era of re-awakened interest and renewed investigation that followed the appearance of the "Origin of Species."

We must now state distinctly and fairly the present views of science regarding man's place in nature. Surely

human evolution is a subject that falls within the scope of zoological investigation, unless indeed it can be shown that the human species is exempt from the control of those laws of nature that hold sway over the animate world elsewhere, unless something can be found which excludes man from the animal kingdom. Notwithstanding the most prolonged search not only by zoologists but as well by those who have been unfriendly to the doctrine of descent, the study of man and of men has revealed nothing essentially unique. What is known of the anatomy, development and fossil relations of man is summarized in the statement that he belongs to the genus and species *Homo sapiens,* placed with the apes and some other forms in the order primates because of agreement in certain peculiar details. The primates agree with the carnivora, rodents and many other orders in the characteristics of the class mammalia, which in turn is only a branch of the limb vertebrata or chordata, which also bears the avaian, reptilian, amphibian and fish branches. And all the vertebrates including man agree with the varied groups of invertebrates in their cellular constitution and in the similar protoplasmic basis of life. As in these structural respects, so in physiological activities and in environmental relations the human species proves more surely with increased knowledge to be only one of the terms in the extensive series of animals. Indeed, the scientific monism of Haeckel and Clifford ventures to assert that man and all other living creatures are one with the mind-stuff of the inorganic world—and this, I believe, is only the logical extension of the genetic and mechanistic hypotheses. However this may be, science holds that human structure is animal structure, and that human lives are biological phenomena.

Man is structurally inferior in many respects to some of his zoological relatives—he is a degenerate, indeed, in many parts of the alimentary, muscular and skeletal sys-

tems—yet he finds in the higher development of his nervous system an advantage that offsets the weaknesses of his constitution elsewhere. He holds his supreme place by virtue only of superior and more effective control of his organization.

Behind their seeming structural differences, only one real distinction can be found to separate man from the apes—the higher development of the brain. The erect posture, the correlated modifications of skeletal and muscular structures, and apparently the powers of speech and reason, seem to be dependent upon the enlargement of this organ, which, so to speak, has pushed the face around under the brain-case. Therefore he who would be ὁ ἄνθρωπος—he who looks ahead—must needs stand erect in order to prevent his eyes from looking straight into the ground. But the most careful analysis has so far failed to detect any essential differences in either structural or functional respects between the human brain and the corresponding organs of the higher apes. In brief, then, differences in degree and not in kind or category seem to distinguish man from the apes—as far as science goes.

Moreover, the human body is a veritable museum of rare and interesting relics of antiquity—the useless vestiges and rudiments of structures that are more developed in other animals. The complete coat of hair of the embryo, the disappearing thirteenth rib, the ape-like and transitory clasping muscle of the new born infant's hand, the curvature of the lower limb and the hand-like foot of the embryo, these and scores of other characters are mutely eloquent witnesses to the past history of change that has brought man to his present place in nature. Embryology gives a vast amount of additional independent testimony. For like all embryo mammals and birds and reptiles, the human embryo possesses gill-slits, and fish-like heart and brain. Above all it begins life as a single cell. Zo-

ology asks:—What can these things mean, if they do *not* mean evolution and a common ancestry with other forms? The objection that no one has ever seen a one-celled organism evolve into a many-celled one, or into a fish or an ape, or into a man, the zoologist answers by placing upon the table the evidence that a single-cell, the human egg, actually does compass the whole history in becoming the almost inconceivably complex adult organism. The process *can* take place for it *does* take place. Paleontology also presents evidence relating to the history of our species, as the third support of the tripod upon which rests the doctrine of human evolution. While opinions differ with respect to the remains of man taken from the many caves and mounds of Europe and America, there is but one generally accepted view regarding the ape-man *Pithecanthropus* of the Javan rocks. The remains of this animal prove among other things that its brain was intermediate between the average ape brain and the average human brain, that the animal was indeed an ape-man and nothing else.

Science holds furthermore that natural factors alone have brought about human evolution. While it is true that the explanation is no more complete for this special instance than it is for animals in general, yet the human species is not exempt from the control of the known factors, like those which cause variation or govern inheritance. Indeed some of the significant facts of heredity have been first made out in the human species. Can we doubt the reality of selection and the struggle for existence when scores perish annually in the conflict with extreme degrees of temperature and other environmental forces, when as a result of the unceasing combat with bacterial enemies alone the casualties on the human side number in our country more than a hundred thousand annually?

To the zoologist it seems strange that there is so much opposition to the doctrine of human evolution. In truth

he finds this to be proportional to misunderstanding of the facts, for when the evidence is produced—Pelion piled on Ossa—any lingering doubts the observer might have are crushed by an irresistible weight of testimony. After all, our kind is but one of the many hundreds of thousands of living species; and viewing the matter from the calm, impersonal standpoint of scientific study, the fact that he is himself a human being does not distort the investigator's vision, for his perspective is corrected and rectified by the instruments of scientific method. He finds no difficulty in accepting human evolution as a scientific fact—that is, true as far as science goes.

In extending its broad comparative studies into the field of complex and intricate human nature, zoology touches numerous other sciences that might seem at first sight to be entirely independent, or at the most only casually connected with it. I shall venture to point out where analysis within the field of zoology has produced results which have a high and immediate value for students of anthropology, psychology, sociology and ethics.

When they deal with the evolution of the human species from pre-human animals, the anthropologist and the zoologist are brought by their similar interest upon common ground; and when they pass on to explore the field of human diversity where lie the complex problems of racial evolution, they are still fellow-workers, for in the case of physical anthropology of human races at least the methods are the same which are employed in zoology generally. Of course it would be absurd for anyone to contend that all the problems of anthropology are strictly zoological questions; to qualify here an investigator must be familiar with linguistics, racial customs and beliefs, and many subjects that are as such apparently outside the

limits of zoology. But unless a sharp line is to be drawn between the slow origin by evolution of the human species and the later history of this species, the comparative and genetic methods of analysis which render the earlier process intelligible can scarcely fail to be of service in dealing with the latter. The great danger, which the zoologist himself clearly sees, arises from a tendency to ignore the detail in formulating the general, to oversimplify the problems of the more recent history. For human conscious elements are so complex and plastic that the problems of racial evolution are rendered far more intricate than the broad zoological analysis of the origin of man as a species.

Psychology, in the second place, is a subject that is related to zoology by the closest of ties, the bond of union being again the common human element. To be sure the zoologist finds enough in his own field to occupy him fully, but the comparative study of nervous systems, and of the reflex, instinctive, intelligent, and reasoned responses of animals brings him inevitably to consider the relation of human mentality and consciousness to the other terms of the animal series. Dealing strictly as a zoologist with animals and their lives, the investigator learns that the machine-like regularity of reflex and instinctive activities is correlated, broadly speaking, with simple nervous organization; that the plasticity of intelligent response is not gained until the physical basis becomes far more complicated; and finally that reason and consciousness are in some way bound up with the higher development of the nerve-centers or ganglia that make up the brain. So the zoologist is inclined to believe that the comparative series of mental grades which culminates in the consciousness, or rather the self-consciousness of the adult human organism, and the series of developmental stages through which the human mental structure passes during infancy and

childhood, indicate an evolution in time of the psychic being of man. Whatever may be the outcome of further study, Romanes, Lloyd Morgan, Forel and Thorndike, among those of modern times, have demonstrated that the genetic methods of zoology are useful instruments for the psychologist, who, I believe, is becoming more and more a student of zoological materials as he realizes the advantage of studying the simpler psychic phenomena of animals lower than man.

In venturing to speak of the relation of zoology to sociology and ethics, I am well aware that I shall be charged with straying beyond the confines of my subject. But if the student of lower forms should find well-defined principles of biological association and principles of animal conduct, it is not only his privilege, it is in a sense his duty as well to bring these to the consideration of the students of human social and ethical relations. Unless in these matters there has been a break in the continuity of evolution, the simpler relations to be observed in lower animals must surely possess a profound interest—and perhaps more.

In a true sense, any of the many-celled animals is a community, whose constituent members are the differentiated tissue-cells, which have undertaken the various tasks of digestion, contraction, sensation, and the rest. By far the majority of animals are cell-communities of this nature. Considering these as individuals, though of a secondary order, we find some communities made up of several animals which have banded together for mutual support and defense, giving us as in the wolf-pack a counterpart of the lowest associations of savage men. But among insects especially we find colonies of numerous multicellular individuals which may be so rigidly specialized for the performance of certain tasks that we cannot avoid the use of terms applied to civilized human groups

in describing their differentiation and division of labor. Some colonies of bees comprise queens and drones and only one kind of sterile workers, though when newly hatched these last serve as guards and nurses, taking the field as foragers for pollen and honey only later in life. In various ant-colonies we will find workers who serve as herdsmen, devoting their time to the care of the ant-cattle or aphids; again there are masons, and gardeners, and carpenters, and soldiers of various ranks, while in the honey-ant some individuals may serve as living receptacles for the tribal stores of food. Each kind undertakes one of the tasks that are vital for the life of the community as a whole. Instinctive and unreasoned their activities may be, and undoubtedly are, but the economic and social relations of the component members of the colony are strikingly analogous to certain fundamental phenomena of human societies. But still more wonderful are the cases that may be found among hornets and wasps. A fertile female overwinters and places her first-laid eggs in the chambers of a simple nest that she constructs herself. When the young of the first brood hatch, she provides them with food, enlarges the nest, and continues the task of egg-laying, while her first offspring relieve her of her former duties as they become able. They enlarge the nest, they care for their younger kin as they hatch, they forage abroad for the food-supplies for the colony. And so the community that begins life in the early spring with a solitary animal advances during the passing weeks to a degree of complexity that is truly astounding. As an epitome of insect social evolution it gives in a few weeks a review of the process that in other forms of social insects with stable colonies, or in the analogous human history, has demanded centuries of time.

As we review these different kinds of individuals—the one-celled animal, the many-celled creature and the community,—we see that each one must obey certain rules of

nature. It must preserve itself, it must perpetuate its kind, and, if it be a member of a higher community, it must act in the interests of others and of the whole group. Do we not find, then, biological definitions of right, and evil, and duty to others as well as to self? Do we not see why altruism has grown out of egoism as communities have evolved at the behest of nature?

But still, facts like these are purely zoological facts. To be well within his rights, the zoologist should perhaps only suggest their usefulness for the analysis of human social relations and obligations. It is for the sociologist and the student of comparative ethics to employ and apply them according to the principles of the genetic method, should they see fit to do so.

In closing, may I say a few words regarding the attitude of the zoologist toward his problems and his results. He may maintain this attitude because of a certain temperament which leads him and his fellows to enter the field of science as investigators. While this may be true, it is also true, I believe, that the subjects of their study, the principles they may discern in nature's order, and their methods of analysis have a profound reflex effect upon not only the contents of their minds but upon their mental machinery as well. The zoologist, like his fellow men of science, learns early that he must adopt an impersonal attitude, for emotion and purely human interest are disturbing elements that prevent him from attaining the purpose of the investigator—which is, to ascertain and verify facts, to classify them logically, so as to derive from them the summaries which like so much "conceptual short-hand" are available for others as well as himself. Science is "organized knowledge," as Pearson defines it; "organized common sense" in Huxley's phrase; and like other men of science the

zoologist learns to view his great common-sensible principles like the doctrine of descent, not as absolute eternal verities, but only as summaries up to date, as working programs, to employ Professor Wilson's concise phrase. This *may* be pragmatism; it is certainly science.

But surely this does not mean that principles like the one mentioned are so many gratuitous assumptions. Like the principle of gravitation and the law of the conservation of energy, zoological laws have the strength and approximate finality of all the wide range of facts that they summarize. And these are many—a vast store of detail and generalization accumulated during decades and centuries by those who have sought upon the mountains or in the abysses of the seas for new knowledge, by countless students who have spent their lives in the field and in the laboratory in the endeavor to pierce still further with trained insight into the mysteries of nature. And these are their results.

No one realizes more than the zoologist that his knowledge is incomplete. No one can see more clearly than he that his intellect evolves, like the great sweeping tide of things and events—the nature he studies and of which he is but a conscious atom. The investigator soon learns to withhold final judgment, agreeing with Clifford that the primary conditions for intellectual development are the plasticity and openness of mind that dogmatism and finality destroy. The end of zoology cannot be until the end of all knowledge.

Conscious then of the impossibility of reaching absolutely final knowledge, why does the investigator continue to search the world of nature as he does? Because of that ingrained and insatiable human curiosity to learn, because of the human discontent with the attained. Antaeus-like, every fresh contact with the world of law and order infuses new energy into his veins for further endeavor. "Und es treibt und reisst ihn fort, rastlos fort . . . " not, it is true,

in the wandering blindness of Schiller's huntsman, for his human vision is aided by the instrument of scientific method with which he can *almost* perceive the infinitely great and the infinitely small.

Glorying in the great achievements of his science, reveling like the mathematician in the ordered assemblage of related and organized knowledge, the student of zoology joins his fellows yet again for a renewed attack upon the distant ramparts of the unknown, deriving courage and inspiration from the motto: ***Ignoramus, in hoc signo laboremus.***